THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

The anatomy of sustainable domestic laundering behaviour

ERIK KLINT

Division of Environmental Systems Analysis
Department of Technology Management and Economics

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2021

The anatomy of sustainable domestic laundering behaviour
ERIK KLINT

Technical report no L2021:129

Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

Main supervisor and examiner: Professor Gregory Peters
Co-supervisor: Professor Lars-Olof Johansson, Gothenburg University

Cover:

Although the white shirt is newly washed, few persons would say that it is clean. Even fewer would feel comfortable wearing it at a formal event, indicating that laundry cleanliness truly is “a state of mind”.

Chalmers Digitaltryck
Gothenburg, Sweden 2021

To my wife Emma and my kids Hilma and Alma
for always keeping my priorities straight in life (and the laundry basket filled up)

The anatomy of sustainable domestic laundering behaviour

ERIK KLINT
Division of Environmental Systems Analysis
Department of Technology Management and Economics
Chalmers University of Technology,

ABSTRACT

Today's washing appliances are much more efficient than those of a decade ago, yet the environmental benefits of this efficiency are counteracted by changes in consumer behaviour. This thesis presents two alternative ways to limit emissions from domestic laundering, as well as to better understand consumer behaviour related to the practice of keeping clothes clean. More specifically, it examines the potential for shared systems (which are common in Sweden) and finds that this setup could reduce climate impacts by at least 26%. Concerning behaviour, the results presented acknowledge that any final laundering practice is influenced by an intricate interaction between technology, social conventions, and individual concerns. Three overarching principles can be identified using current research literature concerning domestic laundry:

1. Technology changes laundry conventions, while social context dictates market acceptance of new cleaning technology.
2. Technological solutions are often suggested to influence laundry behaviour, but individual concerns seem to override the effect of the interventions.
3. Consumer laundry practices are guided by social conventions that are also rooted in intrapersonal dynamics.

Hopefully these principles (as well as the detailed results from the LCA model) could be used to better understand the possibilities and limitations of domestic laundering, and guide any future interventions aiming for a more sustainable society.

Keywords: laundry, behavioural change, interdisciplinary, sharing, consumer psychology, contemporary

ACKNOWLEDGEMENTS

This research has been funded by Formas - a Swedish research council for sustainable development, Electrolux Professional, and HSB to all of which I am grateful for the opportunity getting paid doing this type of work. I am also very grateful for the support of my supervisor Gregory Peters, as well as my co-supervisor Lars-Olof Johansson. I hope that you have found a way to handle my endless request for feedback and discussions (especially since there are several more years to go).

The more you talk with other PhD-students, the more you realize that the work environment and the accepting atmosphere in the Division of Environmental System Analysis (ESA) at Chalmers is quite unique and highly appreciated from my part. Thank you to all current and former colleagues that have put up with my loud twaddle!

Lastly, no good work can be done in isolation. I would like to extend a special thank you to Felipe Bitencourt de Oliveira for taking the time to teach me GaBi (no Article 1 without it), Yommine Hjalmarsson for taking the time to teach me how to do a literature review (no Article 2 without it), Mudit Chordia and Adeline Jerome for giving me input on the draft of this kappa, Henrikke Baumann for challenging me early on to look further than just my nose, and finally Marius Stücheli to help me with all the practical stuff at HSB Living lab as well as taking the time discussing ideas and questions regarding laundry.

Gothenburg, May 2021

Erik Klint

List of publications

This thesis is primarily based on the work described in the following two articles:

Article 1

Klint, E., Peters, G. Sharing is caring - the importance of capital goods when assessing environmental impacts from private and shared laundry systems in Sweden. *Int J Life Cycle Assess* (2021). https://doi.org/10.1007/s11367-021-01890-5

Article 2

Klint, E., Johansson L-O., Peters, G. Triangulating Consumer Behaviour Related to Domestic Laundering – An Interdisciplinary Mapping Review, *Manuscript*

Contribution to appended publications

Article 1 and Article 2

The author carried out the underlying research (e.g. data collection and analysis) and wrote the main bulk of text in each of the articles, with continuous feedback and suggestions for revisions by the co-author(s).

Table of Contents

1. INTRODUCTION

To live is to consume, and to consume is often to pollute one way or another. Everyday activities that satisfy our basic needs are no different, and more than 60% of global greenhouse gas (GHG) emissions can be tied to household consumption (Ivanova et al. 2016). Contributing to these emissions are our regular cleaning of our clothes. On average in Europe, 4-9% of all the energy and 8-12% of all the potable water consumed by households are used for laundering clothes (Pakula and Stamminger 2010).

If we instead look at domestic laundry by focusing on the contribution to environmental impacts from clothing consumption in general, the use-phase is often a period of major water and energy consumption (Muthu 2015, Madsen et al. 2007). At the same time, increased laundering frequency can lead to fibre damage and loss of colour which by extension decrease the lifetime of the clothes (McQueen et al. 2017). This means that laundering is often one of the most important aspects for the final amount of environmental emissions associated with the complete life cycle of a garment (Wiedemann et al. 2020, Moazzem et al. 2018). Due to this large importance of laundry, it would be beneficial if emissions coupled with the practice could be limited and reduced.

Since the invention of the washing machine in the early 20th century, technological advancements have continued to make the operation more user-friendly, e.g. by the automation of the laundering process (Pakula and Stamminger 2015). At the same time, the resource consumption and emissions associated with domestic laundering have been reduced. Some examples of this include:

- The average energy consumption when running a wash cycle has been decreased by more than 50% in Europe during the last 50 years (Presutto et al. 2007).
- The developments of new detergent formulas used in Sweden and Netherlands (going from traditional formulas to ultra-compact formulas) have resulted in a reduction of approximately 50% of both solid waste emission and GHG emissions, just between the years 1988-1998. At the same time, the ingredients used in the newer detergent formulas reduced the human health risk quotient by 40-60% (Saouter and White 2002).
- The phosphorus content in laundry and dishwasher detergents has since 2004 been restricted within the European Union, which has led to a reduced consumption of the chemical by at least 55 000 tonnes per year across the EU (European Commission 2019).

However, as for efficiency measures in general, there is always the risk of a rebound effect since consumer practices tend to coevolve with technological improvements (Shove 2003b). Unfortunately, domestic laundry is no exception. We buy more items of clothing (Peters, Sandin, and Spak 2019) and wash them more frequently than during any other time in history (Klepp 2003). This means that the overall energy consumption associated with domestic laundering has instead been growing steadily in Europe the last 50 years (e.g. by over 100% between 1970 and 2012 in the U.K. (Yates and Evans 2016)). As the reader might suspect, this trend is not only limited to Europe, nor the western world. For example, Wang et al. (2014) writes that while only 5% of the population owned a washing machine in Chinese urban areas during the beginning of 1980s (0% in rural areas), that same number was 97% in 2012 (62% in rural areas). And as consumers in other countries follow suit, so do emissions.

With an increase in the use of chemical and technological aids when laundering (e.g. detergents, washing machines, and tumble dryers), as well as a growing tendency to wash more often, more attention is given to understand the consumers rather than to focusing on technological advancements. Some researchers even argue that most of the potential impact reduction is hampered by the washing habits of the consumers, rather than any additional improvements of the machines (Laitala et al. 2020). For example, many consumers only partially fill the machine when running a cycle due to the fear of overloading, or due to the use of excessively many (and strict) sorting categories (Laitala, Klepp, and Boks 2012). It is also common that consumers fail to adjust the amount of detergent depending on water hardness or the amount of laundry washed, either because of habit or by confusing instructions on the packaging (Järvi and Paloviita 2007).

These challenges and insights regarding behaviour have not gone unnoticed by policymakers. Several recent information campaigns have started targeting consumers themselves (rather than the manufacturer of laundry appliances), encouraging us to make more environmentally friendly choices regarding laundry behaviour (e.g. the *I prefer 30*-campaign). Unfortunately, many of these new attempts have often proved futile. It seems that simply informing consumers about the environmental emissions from laundering and relying on the consumer's (assumed positive) environmental attitudes generates little success (Throne-Holst, Strandbakken, and Stø 2008, Bartiaux 2008).

So, to summarize; technical solutions are counteracted by user behaviour and appealing to the consumers themselves has proven difficult. With this in mind it is obvious that a change in tactics is needed to address this elusive problem with emissions from domestic laundry, but the question remains: in what way?

An extremely simplified view of the problem is to divide it into two parts. First, we have the system that the consumer is using, such as the washing machines, cleaning chemicals etc. Second, we have the consumer herself[1] who makes the decisions when laundering. The articles presented in this licentiate try to tackle the problem from these two alternative viewpoints. The focus of the first article is evaluating the laundering system as a whole, rather than its specific components in isolation (e.g. just looking at the machines). The result from such an evaluation would more clearly show what parts of the system contribute to higher emissions, and how different variables contribute to the final result. The second article tries instead to better understand the consumers. The focus of this article is to take a step back and identify underlying drivers and barriers for changed consumer behaviour associated with laundry practices. This will hopefully lead to a better understanding about laundry practices and facilitate any future interventions towards sustainability. A more detailed description of each of these points of view, and the associated research questions, is presented in the following chapter.

---

[1] Because it is still often a "her" that does the laundry today even though it is the year 2021 (Treas and Tai 2016).

However, with that said it might also be useful to take a step back and reflect upon the validity of the general research agenda to begin with. Looking at the bigger picture, much of the research targeting changed behaviours aim for reducing environmental impacts from human activities as a way to create a more sustainable society. Yet, although domestic laundry contributes to negative environmental impacts, the total levels of emissions varies amongst consumers. In addition, it could be argued that emissions associated with laundry are relatively small compared to other household activities, which seems to be the case in Sweden due to the high amount of renewable energy sources in the grid-mix. This situation creates a dilemma. Since we as consumers only have a limited amount of mental energy (as well as available time) during the day, any intervention for changed laundry behaviour might draw attention from changing other, more polluting, practices (e.g. changed dietary habits). Additionally, forming new habits or changing old ones does not always come easy. Thus, it is not unreasonable to assume that new policies for laundering that target consumer behaviour might result in the consumer "giving up" in forming general sustainable habits (since laundry behaviour is just one of many practices prompted to be changed by policymakers). This means that in practice, although well meant, continuing this research might lead to counterproductive results regarding sustainability issues.

A counter argument would be that by bringing sustainability aspects into laundering habits there is a possibility of spill-over effects from this increased awareness, such as changed behaviours for other types of household practices. Unfortunately, this type of dynamic is quite unusual (Nash et al. 2017). A more common situation is instead that consumers exhibit a type of mental accounting for sustainable behaviours (Hahnel et al. 2020). One such example could be that *"I have now used less detergent when washing clothes for a year, and by doing this I can fly to Barbados during the holiday".* This quid pro quo motivation is usually based on the number of times a behaviour is performed, money spent (e.g. buying ecological produce), or money saved (e.g. by avoiding consumption), rather than the amount of emissions avoided by any of those actions. Changing laundry behaviour (low total emissions) might thus influence consumers to "allow" themselves other more polluting behaviours, such as buying new technological gadgets or consuming more meat (high total emissions).

Given this situation it might instead be more suitable to pursue technological interventions for domestic laundering that are so far upstream in the garment life cycle they are unaffected by consumer decisions. For example, greenhouse gas emissions from laundry practices in Europe vary by a factor of 6.5 between countries, mostly depending on the energy source (Shahmohammadi et al. 2017). A rapid transition to clean energy production globally would thus lead to a major reduction in greenhouse emissions from laundry practices, regardless of any variability of consumer behaviour.

My personal opinion is that from a purely emission-based point of view, domestic laundry research might very well be of lower importance due to the reasoning in the previous paragraphs. With that said, there are some unique aspects with this type of research that outweigh this ethical dilemma and merit further studies. First of all, laundering is inevitably connected to a much larger system of environmental impacts from clothing care, and by extension clothing consumption. For example, as noted earlier in the introduction increased laundering frequency will decrease the lifetime of the clothes (McQueen et al. 2017), forcing consumers to buy new apparel more often or reducing the lifespan of garments in the secondhand market. This means that while the direct emissions from the laundering process might be lower, potential indirect environmental impacts from increased clothing consumption are certainly much higher.

Secondly, when working with laundry research you soon realise that the subject is very relatable for almost everyone. This in turn often leads to a high engagement when discussing it (and by extension sustainability) with a broader public. At the same time, the emissions (and also cost) of the practice are often hidden. Additionally, laundering seems to be heavily rooted in social acceptance by having clean clothes, rather than performing the practice in a sustainable way. This means that there is a high probability that the findings from this field are transferrable to other types of behaviours with the same characteristics (i.e. practices that are relatable, have a hidden emissions or cost, and stems from a social context rather than environmental goals). If these other types of behaviours result in high emissions, general findings from laundry research could thus potentially be used to discuss and limit these otherwise intangible behaviours. Depending on the consumer groups, some speculative examples of where there could be an overlap with behavioural changes of laundry practices include: some types of transportation, water consumption, eating at a restaurant or buying take-away, home-delivery of products etc. However, to what extent these potential behavioural overlaps exists, and are possible to influence using knowledge from laundry research, remains to be seen.

2. RESEARCH QUESTIONS

As mentioned in the introduction, this licentiate tries to address laundry practices from two alternative viewpoints. The first two research questions (RQ1 and RQ2) relate to the laundering system from a more holistic viewpoint, while the third research question (RQ3) instead tries to better understand us as consumers.

2.1. RQ1 and RQ2: Alternative systems for doing the laundry

Previous studies assume that consumers use their own washing machine within their private home. Although this might be the most common setup, there are some alternative ways the domestic laundering can be performed. Handwashing and commercial dry-cleaning facilities aside, some researchers argue that one alterative way to influence environmental impacts could be to move from private ownership of laundry machines, to a community-based system (CBS) or a product service system (PSS) for laundry activities (Tukker 2015, Mont and Plepys 2007). Since these setups use fewer (but more robust) machines per consumer, it is argued that this solution could limit environmental impacts.

CBS and PSS solutions for laundering (from here on called shared systems) are not a novel way of cleaning your clothes. On the contrary, these types of solutions are common in many countries, especially in more densely populated areas. For example, shared laundries (e.g. communal laundry rooms within a multi-family building or a commercial coin-operated facility) are often used in the Philippines (Retamal and Schandl 2018), Japan and Thailand (Moon, Amasawa, and Hirao 2020), and Finland (Miilunpalo and Raisanen 2019). A recent study by Laitala et al. (2020) also found that 6-13% of consumers in China, Germany, Japan, UK, and the USA make use of a shared washing machine regularly. In Sweden, shared laundries have been the norm throughout the nation since the 1950s although a shift is currently underway (Lund 2009). Today, most newly built multi-family buildings in Sweden are instead equipped with private, in-unit washing machines.

However, in general, creating shared systems for different kinds of products or services does not always lead to decreased environmental impacts. Instead, the devil is in the contextual details. This means that the resource consumption and coupled emissions will vary considerably depending on where in the world a shared system is introduced, which also applies for laundering (Retamal and Schandl 2018). For example, it is not possible to just compare the specific change of machine types. Instead, other aspects that must be considered are also the altered material consumption associated with the building itself, as well as any impacts from altered consumer behaviour (e.g. dosage of cleaning chemicals and tap water used during the wash cycle). Unfortunately, many previous published studies concerning shared systems for domestic laundry do not include these aspects (Borg and Hogberg 2014).

The first article in this licentiate tries to address these missing aspects. It expands the analytical system boundary from only looking at energy consumption by the machine themselves, to also include the space used in the building, as well as any consumable goods expended when running a wash cycle. This enables a clearer comparison between private and shared laundry systems while at the same time answering the first research question:

RQ1 – *To what extent do capital goods (i.e. whitegoods and the building itself) influence the emissions associated with domestic laundry in Sweden, and how do they vary between private and shared laundry systems?*

The setup described in the first article also allows for another type of comparison, namely the trade-off between detergent dose and wash temperature (i.e. energy consumption). This important to understand because of the ongoing initiatives that tries to influence consumers into washing at lower temperatures for environmental reasons. Since lower wash temperatures often lead to unsatisfactory cleaning results, some consumers might be inclined to compensate the shift in temperature with a larger dose of detergent. The second research question thus becomes:

RQ2 – *How could net emissions potentially change in Sweden, as well as in other EU countries, on account of the trade-off between temperature and detergent dose?*

Answering this question will hopefully make it clear if this trade-off is beneficial from an environmental point of view, and by extension whether the current campaigns are potentially counterproductive.

2.2. RQ3: Underlying drivers and barriers for consumer behaviour

One alterative way of addressing emissions from domestic laundering could instead be to move away from the technical perspective, focusing more on the main influencer of the practice: the consumers themselves. Since the emissions from domestic laundry are intricately entangled with the final decisions of the person using the machines (e.g. wash frequency, amount of detergent used, how much laundry the machine is filled with, choice of drying method etc.), changing consumer behaviour will directly influence environmental emissions.

Unfortunately, few consumers express any willingness to change their washing and drying habits (Uitdenbogerd 2007) or believe that doing the laundry leads to any emissions that could affect the environment (Arild 2003). Taking this into account, it is no surprise that previous interventions for sustainable change regarding laundry practices failed. However, these failures might also indicate a lack of clarity regarding the underlying drivers and barriers for laundry practices *in general,* let alone from a sustainability perspective (i.e. why do most people wash their clothes in a specific way to begin with?).

Since changing laundering behavior seems so difficult, authors from different research fields have called for interdisciplinary approaches (Conrady, Kruschwitz, and Stamminger 2013, Yates and Evans 2016). The hope is that such studies may better explain the workings of consumer practices and its underlying motivations. To facilitate such interdisciplinarity, the second article aims to describe and summarize current research findings. More specifically, it aims to review the literature to answer the question:

RQ3 – *What underlying factors shape contemporary laundry behaviour?*

Hopefully, answering this question will establish a better baseline for future research within the field, and guide new policies aiming for a more sustainable society.

3. THEORETICAL BACKGROUND

This chapter gives a brief introduction to the main methodological choices made in Article 1 and 2.

3.1. Life cycle assessment (LCA)

Several methods can be used when assessing environmental impacts from human activities. For example, common methods and tools include Material Flow Analysis (MFA), Input-Output Analysis (IOA), and Environmental Impacts Assessment (EIA). To answer the first two research questions, the analysis and model created in Article 1 uses Life cycle Assessment (LCA); since this tool is well suited for looking at environmental impacts for products and services (Finnveden and Moberg 2005).

Initially, LCA was developed during the early 1970s as tool to evaluate a single product. However, the methodology has evolved throughout the years and today more and more LCA are driven by policy issues (McManus and Taylor 2015). According to ISO 14040:2006, four major steps should be considered when creating an LCA, see Fig 1.

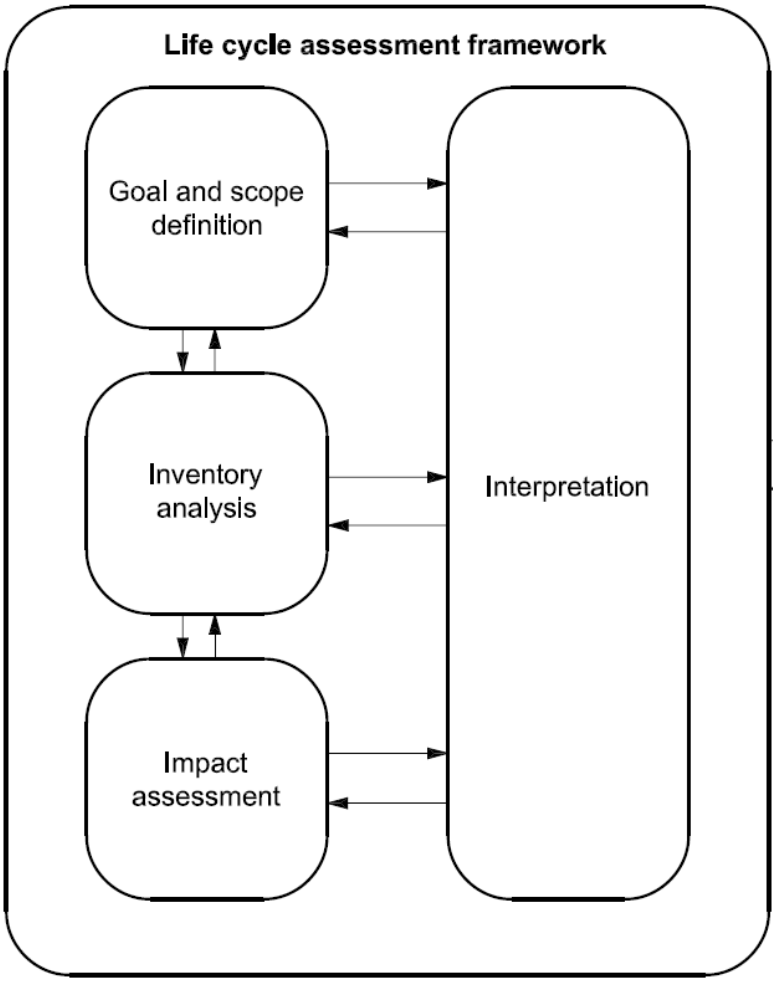

Fig 1. The LCA framework (ISO 2006).

These four steps include:

1. **Goal and Scope definition** – The initial step is to define the context where the analysis take place, as well as the focus of the study. Some questions that should be answered are why the analysis is created, which questions the study intend to answer, who the stakeholders are, etc. Additionally, the physical, temporal, and procedural limitations for the analysis need to be defined. Connected to this, a functional unit must be chosen. This is a quantitative explanation of the product or service for which the analysis is performed. Examples of a functional unit might be person-km (e.g. for LCA regarding transportation alternatives), or one kg of laundry washed and dried (as for Article 1). When defining the goal and scope it is often helpful to create a flowchart illustrating the LCA model. Depending on the system boundary for the analysis, the flowchart might encompass the complete life cycle of a product or service from cradle (i.e. raw material acquisition) to grave (i.e. waste management), but it can also be adapted to only include parts of the complete life cycle or limited to a specific process.
2. **Inventory analysis** – Following the goal and scope, the aim of the inventory analysis is to quantify all the relevant processes and flows for the LCA (e.g. materials, emissions, energy etc.). The outcome from the step is the life cycle inventory (LCI), which is a list of all the flows described by the functional unit. In this way, the functional unit is used to determine the reference flow for the model and scale the data and resulting flows accordingly. Of special interest is any flow that crosses the system boundary (so-called elementary flows) since these flows are used in the impact assessment to quantify the potential environmental impacts.
3. **Impact assessment** – The final analytical step is to assess the magnitude of contribution of each elementary flow to an impact on the environment (Hauschild, Rosenbaum, and Olsen 2018). In practice, this translation of the LCI into the life cycle impact assessment (LCIA) is almost always computerized due to the high complexity of the characterization models used by the software. Even so, according to ISO 14040:2006, the impact assessment does include some mandatory and optional steps that the practitioner should reflect upon. The mandatory steps include: *Selection of impact categories* (i.e. which impacts should be include in the analysis?), *Classification* (i.e. which impact categories does the LCI affect?), and *Characterisation* (i.e. how much does each LCI contribute to the result?). The optional steps include: *Normalisation* (i.e. comparing the results to a point of reference), *Weighting* (i.e. assigning a priority or relative importance of each impact category), and *Grouping* (i.e. aggregating the results).
4. **Interpretation** – Many times, creating a LCA can be regarded as a learning process in addition to an analytical activity (Baumann and Tillman 2004). This means that interpretation is needed throughout the process (i.e. not only when presenting the results) and that LCA should be regarded as an iterative tool.

In more general terms, depending on the goal and scope of the analysis a LCA can be created with a retrospective focus (e.g. for learning about a current system and prioritising areas for improvements) or with a prospective focus (e.g. understanding how possible future scenarios might affect environmental impacts). Both perspectives have implications for analytical decisions such as data collection (Tillman 2000). Additionally, LCA are often divided between attributional LCA (ALCA) and consequential LCA (CLCA). The focus of an ALCA is to estimate the environmental impact that can be tied to a specific product or service. The starting point for a CLCA is in turn to estimate the *change* of environmental impact related to a possible decision of producing, and using, an additional amount of the product or service (Ekvall 2020).

The analysis in this licentiate (i.e. Article 1) can be categorized as an attributional LCA. This means that the results presented tries to reflect how the situation look today, using average values to estimate impacts from two main laundry setups (private and shared systems for domestic laundering).

3.2. Literature review

The general aim of a literature reviews is to make sense of large bodies of information, and by doing so answering questions about what works and what does not work according to the reviewed material (Petticrew, Roberts, and Wiley 2006). Depending on the available resources and the need for quality regarding the results of the literature review, a number of different approaches are available. For example, if the aim is to summarize the best available evidence for a specific question while identifying implications for further research, a simple evidence summary might suffice. Such an analysis will often take around 1-3 weeks to finalize. If, however, more rigorous results are needed (e.g. when reviewing evidence of possible side-effects from new drugs) the required time for performing the analysis is much higher (up to two years). These types of reviews include: *Meta-analysis* (a statistical analysis that aim to combine the findings from independent studies), *Realist synthesis* (identifying underlying causal mechanisms in real life scenarios and explore possible conditions for the results), and *Systematic reviews of quantitative and/or qualitative evidence* (a thorough summary of the available research on a given topic) (Booth 2016).

To answer the third research question, a mapping review was performed in Article 2 regarding laundry behaviour. The aim of a mapping review is to categorize existing research literature and to map out any general trends or missing areas of interest. This result can then be used to commission further research (Grant and Booth 2009). According to Budgen et al. (2008), mapping reviews consist of three stages:

1. Creating a search strategy to identify any primary studies that may contain relevant results
2. Examine the identified studies in more detail, excluding any studies that fall outside the scope of the research question
3. *where appropriate*: Performing a quality assessment of the selected studies

Note that these stages are rather generic, especially compared to other types of literature reviews, which mean that the practitioner needs to be careful when describing the specific methodological choices. In any case, the sign of a good mapping review is if the results gives the reader a good understanding of the chronological development of the literature (i.e. when was the research performed?), while also illustrating any spatial variability (i.e. where was the research performed?) in addition to the general findings (Anderson et al. 2008).

3.3. Laundry practices

The desire to understand the practice of doing the laundry is not new in itself. For example, Shove (2003b) makes a point that laundry practices are sustained by a distinctive blend of ideas about sensation, display, disinfection, and deodorization. This means that the practice of laundering amongst consumers might look similar on the surface, but in reality, it is created by: (for each individual) a specific combination of meaning, moral and symbolic significance, technology, and experience (Shove 2003a). To understand laundering, one must therefore consider all these different aspects as well as any physical and temporal limitations, creating a whirlpool-model of the practice depicted in Fig 2.

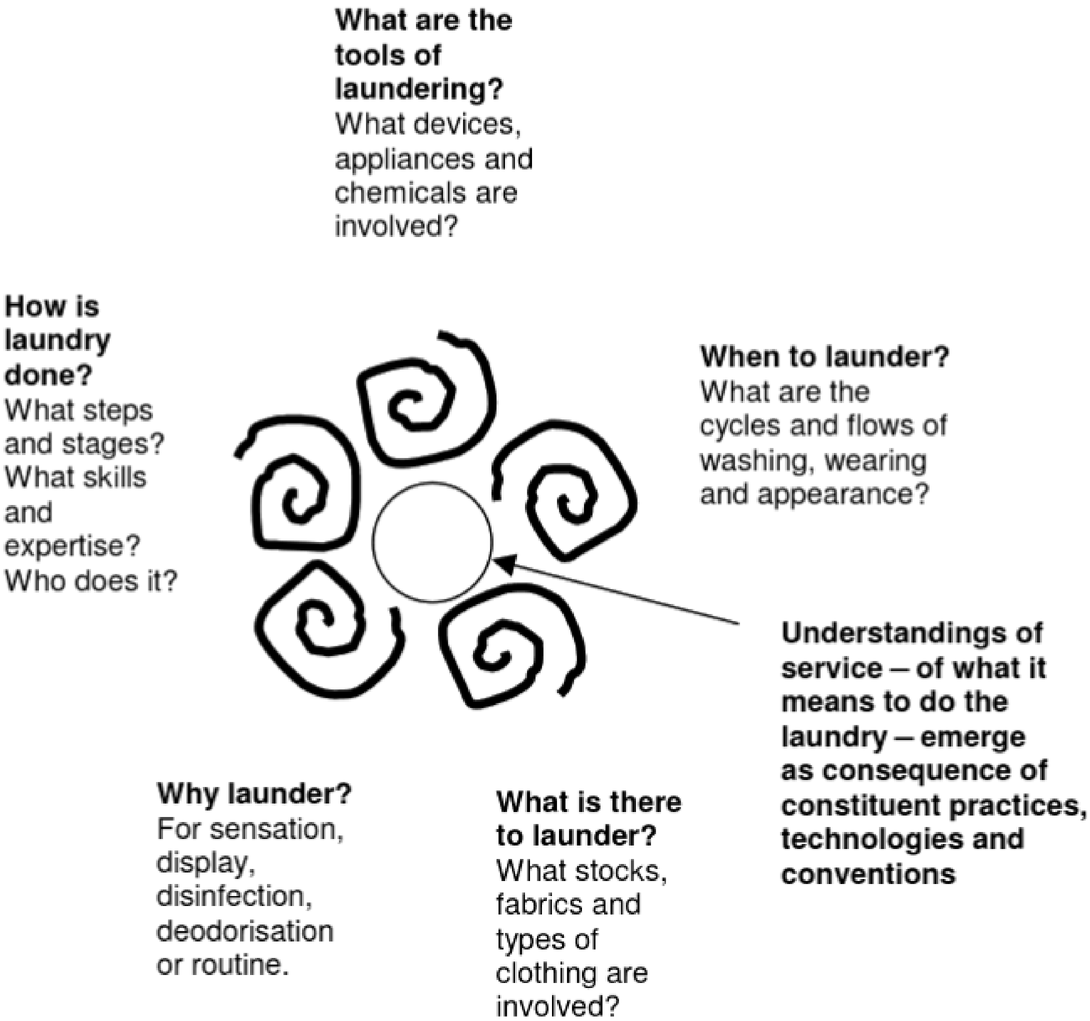

Fig 2. A whirlpool model of laundry (Shove 2003a).

While helpful, the model presented in Fig 2 is in some sense too specific to be used as a sole basis for synthesising findings from different research fields. However, Shove (2003a) also notes that any sociotechnical system (such as laundering) can be described by the devices, systems, and practices populating the system. In such a model, it is often the coevolution and relationships between these categories (i.e. the so-called "dimensions" in Fig 3) that are of special interest.

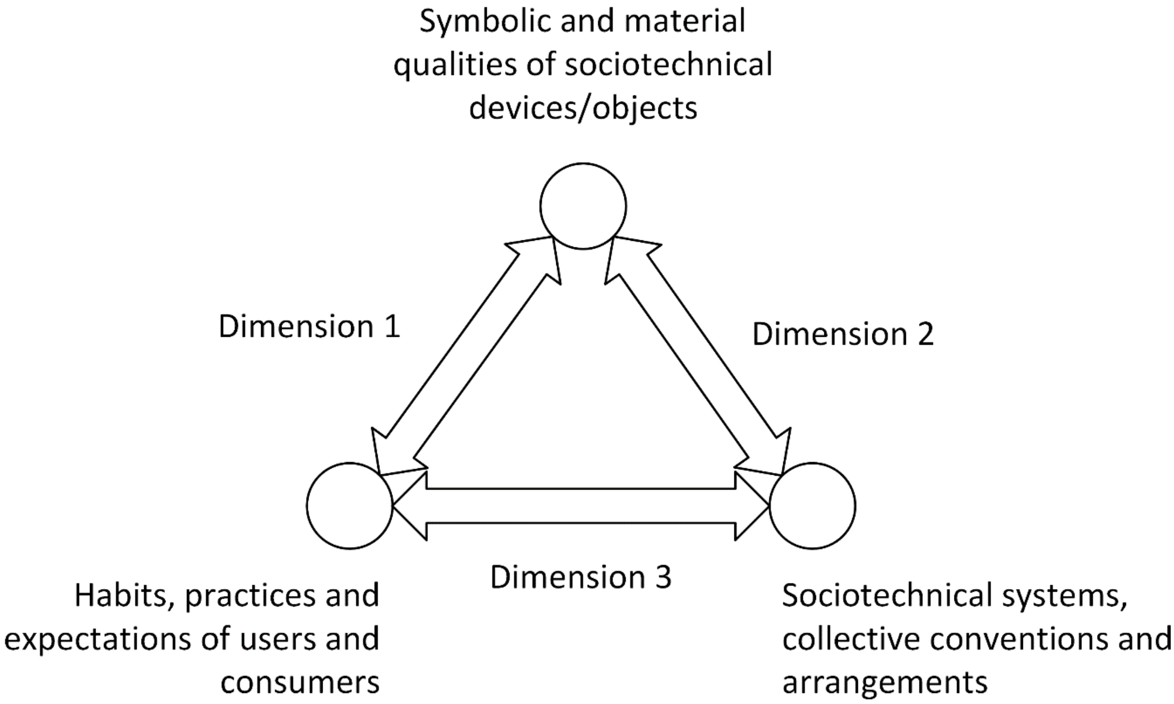

Fig 3. Three dimensions of co-evolution of sociotechnical systems (Shove 2003a).

Consider for example a car. The car itself is can be said to have high material qualities (e.g. the technical aspects of the engine) and symbolic qualities (e.g. associating ownership with freedom and a high standard of living). At the same time, the introduction of cars requires some basic societal arrangement (e.g. roads and parking spaces) while also creating new consumer habits (e.g. the possibility of taking the car to work rather than the bus). While each aspect is interesting, another possibility is to look at the interplay and co-evolution over time. For example, as cars become cheaper more people might be inclined to use one for commuting to work, increasing congestion, and shaping political initiatives for more advanced traffic solutions (dimension 3). This advancement of infrastructure might allow for higher speed without reducing the risk for accidents, steering possible technological advancements for the vehicle industry (dimension 2). This, in turn, changes consumer expectations of what values a car should fulfil (dimension 1) and thus reinforcing the cycle. Of course, this is a highly simplified example of a much more complex system. However, it does illustrate that from a sustainability perspective it does not always make any sense to solely look at one of these aspects (e.g. the average fuel consumption for a specific car model at a specific time in history), since the final environmental impact will be a result of the sociotechnical system as a whole.

To continuing this previous work on laundry practices, the analysis presented in the second article is thus guided by both of these models presented in Fig 2 and Fig 3. Hopefully this will facilitate the integrations of results between different research fields for the reader, as well as lead to a better understanding of what it means to do the laundry.

4. APPLIED METHODS IN CURRENT ARTICLES

This chapter briefly describes the general methods for Article 1 and 2. More details about methodological choices can be found in each article respectively.

4.1. Evaluating alternative systems for doing the laundry

To answer RQ1 and RQ2, three attributional LCAs (two types of shared systems and one type of private system) were created with the overall goal of illustrating and comparing the environmental impacts of laundry activities. The functional unit in the study was chosen to be the washing and drying of 1 kg of clothing, to facilitate future comparisons with other life-cycle studies regarding laundry (as well as facilitate a potential incorporation of the results into LCA for clothing). The scope of the study included a cradle-to-grave analysis for the capital goods, the cleaning chemicals used for a wash cycle, in addition to the consumption of energy and water when washing and drying. The system boundary is depicted in Fig 4.

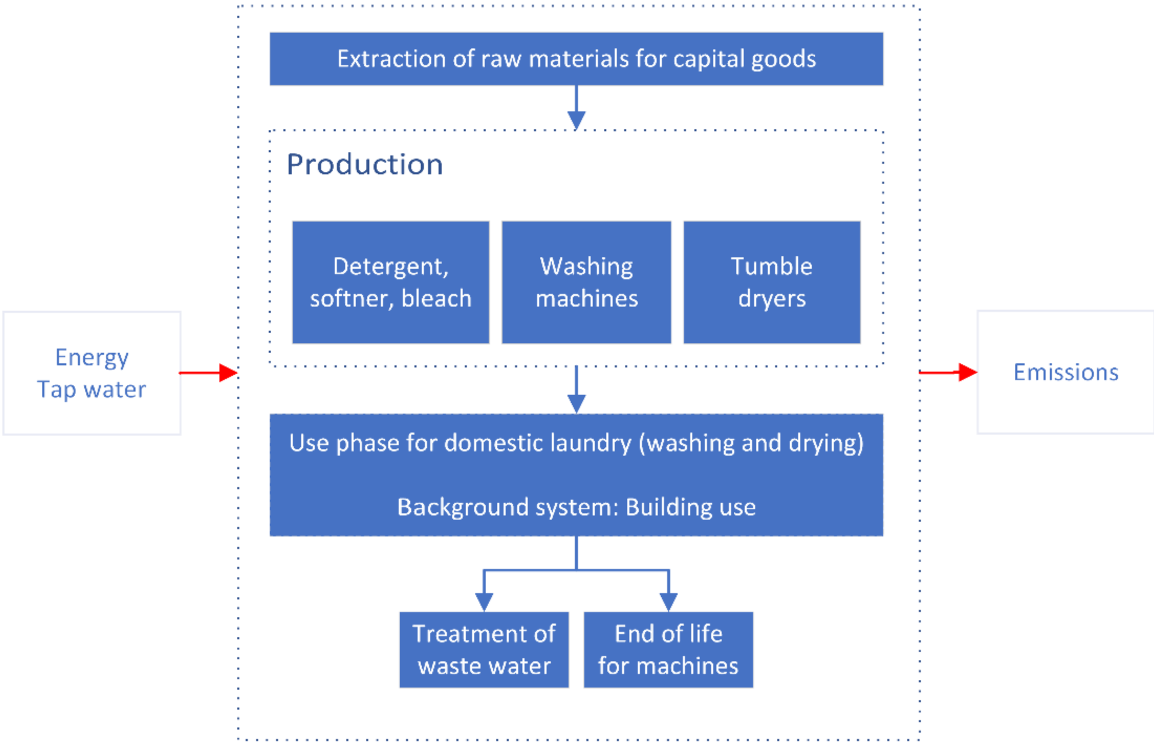

Fig 4. The system boundary of the LCA model in Article 1

The main difference between the two types of shared systems was the choice of washing machine, whereas the choice of machine model for the tumble dryer was the same, see Table 1. The data used in all the three systems regarding the machines (e.g. bill of materials and resource consumption per wash and dry cycle) was taken directly from the European Commission reports on preparatory studies for Eco-design Requirements (EuP). This data was deemed appropriated since the reports give a thorough review of the European market for whitegoods, while at the same time distinguishing between private washing machines and dryers (Presutto et al. 2007, PricewaterhouseCoopers 2009), and professional ones (Graulich et al. 2011).

Currently, newly built apartments in Sweden are usually pre-equipped with a private washing machine and a tumble dryer (i.e. a “washing pillar”). Thus, to make the result comparable between the private and shared systems, it was assumed that the residents, regardless of system, would choose to use a tumble dryer instead of drying the clothes using a drying cabinet or by hanging it on a line (either inside the building or outside). Additionally, to avoid underestimating environmental impacts, it was assumed that the consumer would load the machine to 60% of the machine size. This value can be compared to the average values for European households, in which consumers have been reported to load washing machines at 60-68% of the rated capacity (Presutto et al. 2007).

Finally, environmental impacts from building usage within each system were modelled on the basis of the floor area used. Emissions associated with the building itself were taken from a cradle-to-grave LCA-report deemed representative for newly built energy efficient multi-family concrete houses in Sweden (Liljenström et al. 2015). The size of the shared laundries were in turn estimated from floorplans for newly built shared facilities in Sweden (Rotocon 2019). According to these floorplans, a shared facility occupies approximately 15 m^2 and is equipped with three washing machines and three tumble dryers (i.e. 5 m^2 floor area per washing pillar). For the private system, the washing pillar was assumed to use 1 m^2 floor area. A summary of the data used in each system can be found in Table 1.

Table 1. Summary of the characteristics of each laundry system.

Specifications	**Private laundry**	**Shared laundry 1**	**Shared laundry 2**
Washing machine load capacity	5 kg	6 kg	10 kg
Loading rate (amount of laundry)	60% (3 kg)	60% (3.6 kg)	60% (6 kg)
Type of washing machine	Private	Semi-professional	Professional
Average no. cycles during lifetime for washing machine	1100	11000	24000
Tumble dryer size	6 kg	6 kg	6 kg[2]
Type of tumble dryer	Private air condenser	Semi-professional air condenser	Semi-professional air condenser
Average no. cycles during lifetime for tumble dryer	900	11000	11000
Floor area used [m^2] per washing pillar	1	5	5
Average resource consumption for one standard load, washed and dried			
- Energy [MJ]	11.18	11.92	20.79[2]
- Water [L]	44.49	47.66	97.08
- Detergent [g]	66	85.8	132

To better understand the robustness of the model, as well as how important the different variables were for the final result, a sensitivity analysis was also simulated for the following variables*:* ***wash temperature*** (30°C, 40°C, 60°C, or 90°C), ***type of building*** (low, moderate, or high emissions per m^2), and ***room size for the shared laundries*** (10 m^2, 15 m^2, or 25 m^2 heated floor area). Additionally, to the answer the second research question one more simulation regarding ***energy versus detergent*** were performed using the private system as a baseline. The underlying motivation for this simulation was that previous authors have demonstrated a great variability in emissions of greenhouse gases (GHG) from domestic laundry. This variability was mainly dependent on the extent to which the electricity supply in the country in question was based on non-renewable resources, or if the amount of detergent used per wash was high (as often is the case in regions with hard water). These variations in GHG emission could sometimes be as large as a factor 6.5 between European countries, and by a factor 3.5-5 within each country (Shahmohammadi et al. 2017).

The cleaning properties of a wash program are a result of mechanical stress, chemical use, temperature, and time (Sinner 1960). However, the effectiveness of most of today's detergents varies with temperature and higher temperature often means better cleaning

[2] Since the size of the tumble dryer is smaller than the washing machine, it was assumed that the dryer was used 1.67 times per standard load for shared laundry 2.

results. This would mean that in theory, a smaller amount of detergent could be used for warmer wash-cycles (Stamminger, Barth, and Dörr 2005). The aim of the final simulation was therefore to investigate this trade-off between energy and detergent, while at the same time accounting for variability in energy source (i.e. non-renewable or renewable) within the EU. In practical terms, GHG emissions were calculated using two different countries representing European extremes for electricity supply (Poland and Sweden), as well as for the European average. The amount of detergent was in turn assumed to follow the recommendations for soft water or hard water (i.e. +/- 50% the rated dose of detergent), as to better encompass the limits of variability. The resulting changes in GHG emissions from this simulation could thus be used to outline the extremes, as well as the average, trade-off between energy usage and detergent dosage within the EU.

4.2. Evaluating consumer behaviour

Due to the complexity of human nature there are no certain way to pinpoint specific causal relationship between motivation (i.e. drivers and barriers) and behaviour for laundering. Instead, a first step to answer the third research question was to paint a picture of current scientific knowledge, identifying any common behavioural themes (as well as outliers) regarding our relationship with laundry. This was done in the second article by performing a mapping review (Grant and Booth 2009, Petticrew, Roberts, and Wiley 2006, Booth 2016).

Initially, a search string was developed with a focus on laundry and consumer motivations connected to laundering. Using keywords from already known sources within the field, eight blocks of strings were created:

1. Laundr* OR Clothes OR Apparel* OR Linen*
2. Wash* OR Clean* OR Laundr* OR "Soil removal"
3. "Washing machine" OR "Tumble dryer" OR "Drying cabinet" OR "Household appliance"
4. "Laundry room" OR Laundromat OR Launderette
5. Psycholo* OR Cleanliness* OR Driver* OR Barrier* OR "Psychological factor*"
6. Habit* OR Behaviour* OR Practice* OR Action* OR Pattern* OR Routine* OR Attitude*
7. Tradition* OR Culture* OR Convention* OR Inconspicious OR Conspicious
8. "Personal hygiene" OR "Shower*"

Combinations of these blocks were then used in Scopus as well as in ProQuest on the 1st of February 2021. Search results were limited to published articles in English up until that day. A complete search string for Scopus and ProQuest, as well as a description of the filtering of the initial search result, can be found in the appendix.

The search strings generated 1554 articles in Scopus and 1492 articles in ProQuest. After removing the duplicates at total of 2544 articles remained. The titles and abstracts of these articles were then skimmed to eliminate any articles that did not focus on consumers in relationship to laundering practices, clothes, detergent, or personal hygiene (i.e. excluding any articles focusing on mental health patients, product brand marketing, elderly care, purely technical and chemical investigations, laundry solutions for health care, industrial laundering etc.). After this initial screening 323 articles remained.

The second screening involved reading through the abstracts in more detail and excluding articles that failed to focus on neither of the following:

- Dirt or cleanliness in relationship to clothes, laundry, or laundering
- Behaviour, emotions, values, attitude in relationship to dirty clothes, laundry, or laundering
- Personal cleanliness practices that could be attributed to clothes, laundry, or laundering from a social or moral perspective.

After the second screening 68 articles remained, which were then read in full. Out of these, 7 were deemed out of scope (e.g. focusing more on clothing consumption in general). Lastly, additional records were identified using the remaining 61 articles' reference lists, as well as their citation patterns in Scopus and in the Web of Science. This method identified an additional 47 articles that was deemed potentially relevant, although only 18 were included in the final analysis after being read in full. All in all, a total of 108 journal articles were read in full, and of these 79 were included in the qualitative synthesis. See Fig 5 for an overview of the workflow.

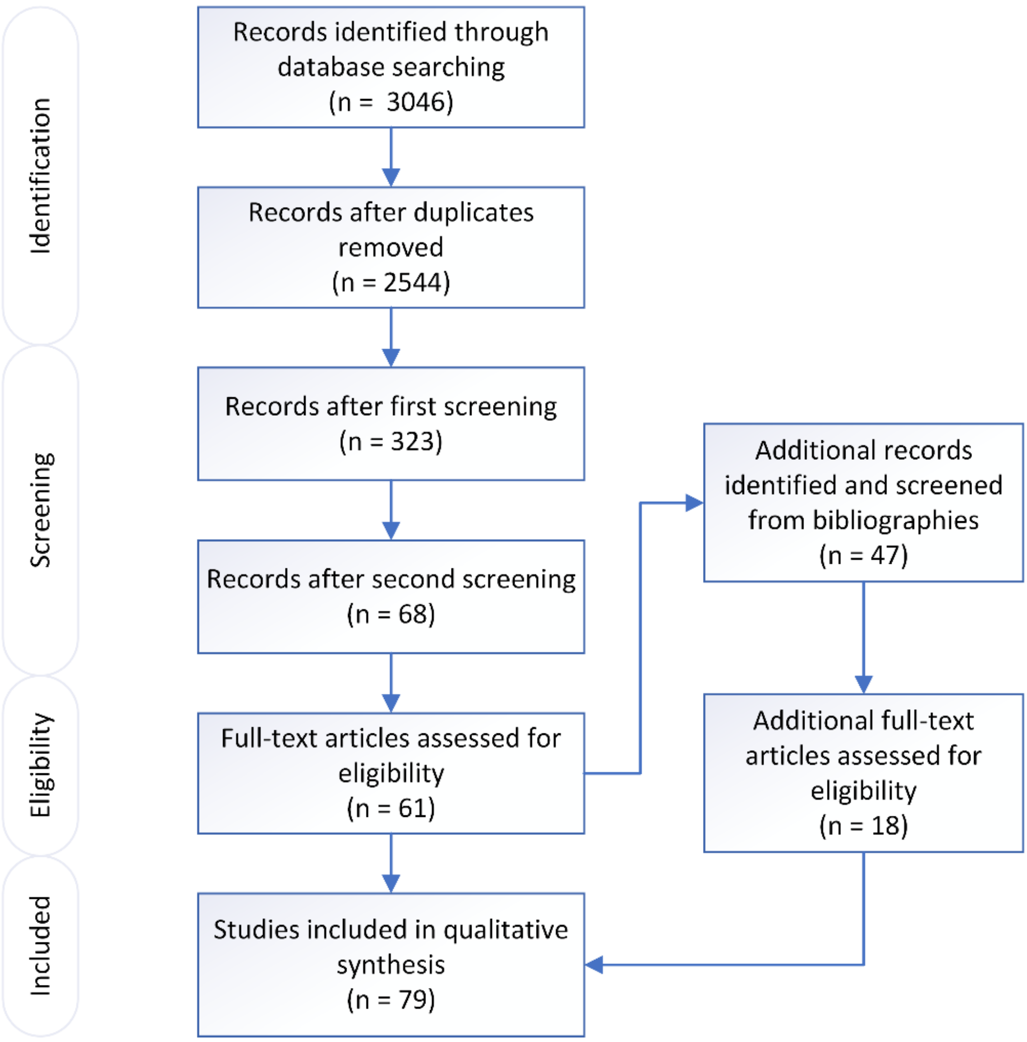

Fig 5. Workflow and results for the literature review. Adapted from Moher et al. (2009).

5. SUMMARY OF RESULTS

This chapter briefly describes the results from Article 1 and 2. More detailed results can be found in each article respectively.

5.1. Capital goods are important when estimating emissions from laundering

The GHG emissions associated with domestic laundry for the three different laundry systems are shown in Fig 6. The impact for each system is different, with the shared systems resulting in levels of emissions approximately 26% lower than the private one (190 g CO_2 eq./kg for the private laundry, compared to 147 g CO_2 eq./kg and 136 g CO_2 eq./kg for the shared laundry 1 and 2 respectively).

Reflecting of the first research question, it is evident that capital goods play a much larger role for emissions from laundering than previously thought. This is especially true for the private system were emissions from capital goods represented approx. 38% of total GHG emissions, see Table 2. For the shared systems, the greatest contributor was instead the use of detergent (approx. 33% of total GHG emissions).

As Fig 6 indicates, the higher number of potential wash cycles indicated in Table 1 completely offsets the additional materials used by the larger, more robust machines in the shared systems. Additionally, by comparing the contribution to GHG emissions from the different capital goods we can conclude that the building characteristics are as important as the washing machine and tumble dryer themselves, see Fig 7.

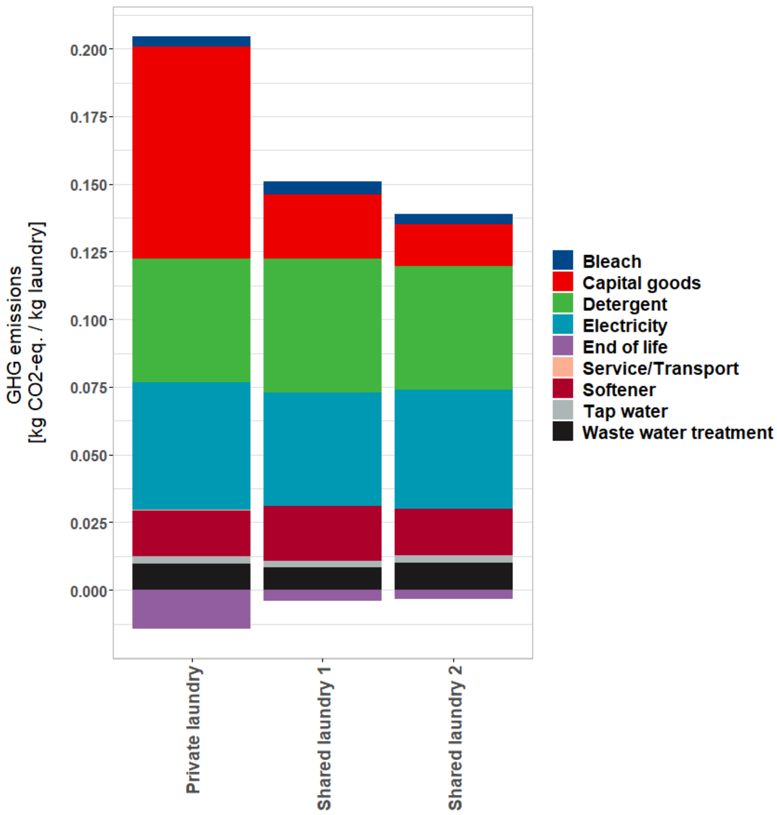

Fig 6. Resulting GHG emissions from domestic laundry for each system

Table 2. Relative contribution to GHG emissions for each of the LCA processes for one standard load, washed and dried. The two largest contributors for each system are highlighted in red.

LCA process	**Private laundry**	**Shared laundry 1**	**Shared laundry 2**
Bleach	1.9%	3.0%	2.7%
Capital goods	38.3%	15.8%	11.3%
Detergent	22.3%	32.8%	32.9%
Electricity	23.0%	27.7%	31.5%
End of life	-7.0%	-2.6%	-2.4%
Service/Transport	0.1%	0.0%	0.0%
Softener	8.3%	13.6%	12.3%
Tap water	1.3%	1.5%	2.1%
Wastewater treatment	4.7%	5.5%	7.3%

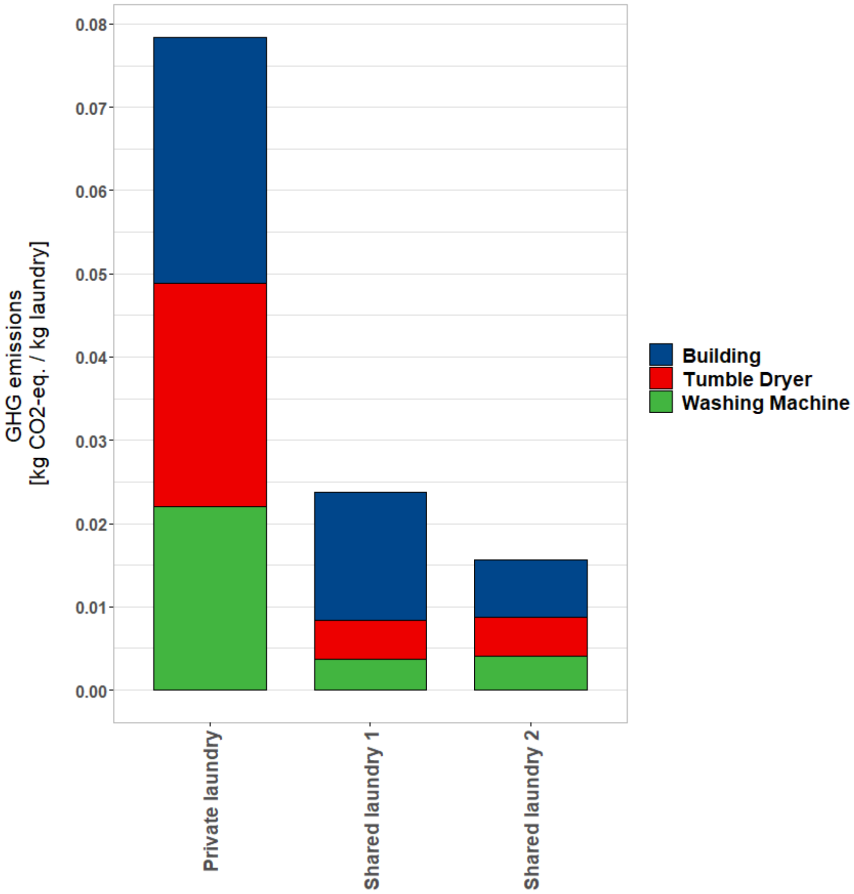

Fig 7. Calculated GHG emissions from capital goods.

The sensitively analysis of the LCA model also yielded interesting results, see Fig 8. According to the results from the simulation, it is evident that changes in the building characteristics influence the GHG emissions to a similar extent as changes in choice of wash temperature. The same goes for the size of the laundry room used by the shared systems.

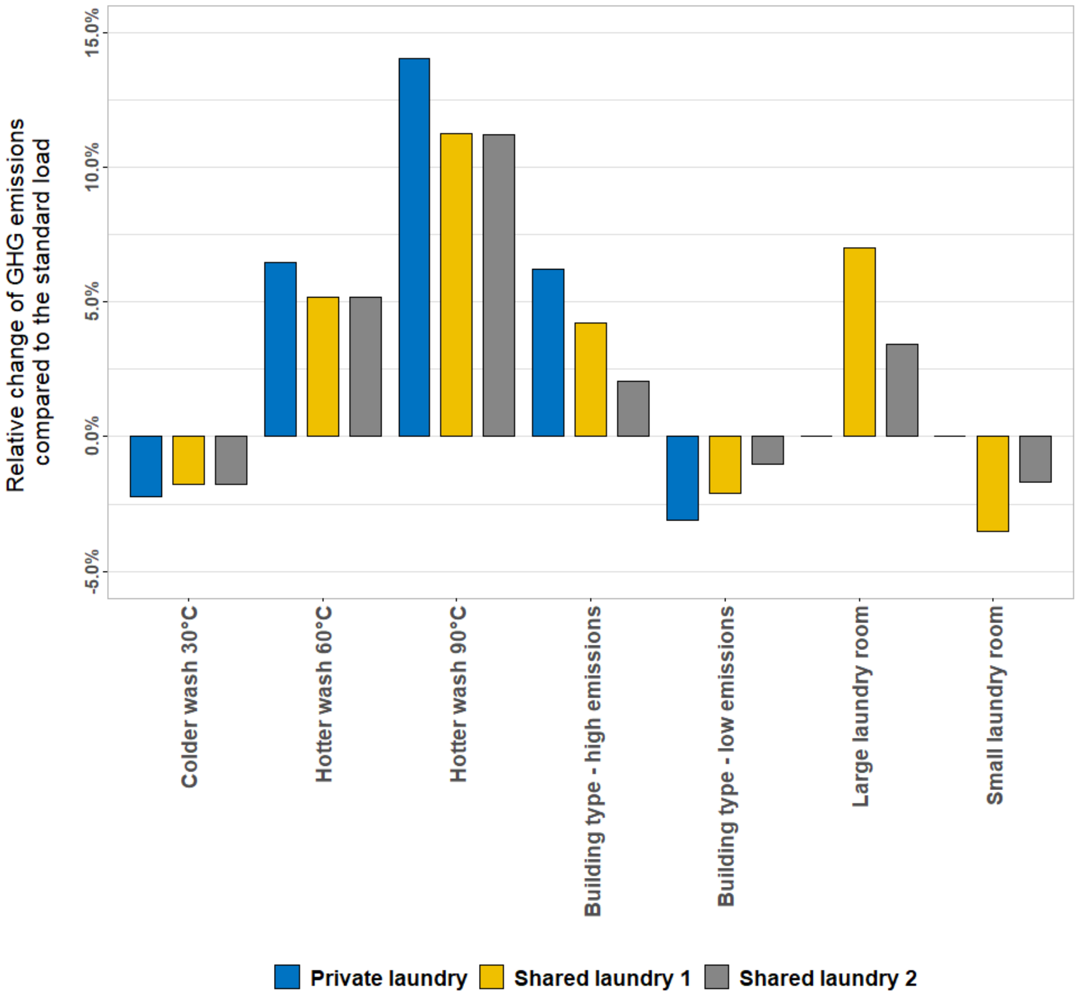

Fig 8. Changes in GHG emissions due to different wash temperature, type of building, or size of the laundry room.

As for the second research question, the resulting changes to GHG emissions (relative to a standard 40°C program) associated with the electricity versus detergent trade-off are depicted in Fig 9. Each colour in the figure represent a different energy source (European averages, Sweden, or Poland). In turn, the shape of the dots represents a different amount of detergent depending on whether the water is soft (triangle) or hard (circle). All changes are normalized towards the emissions associated with a standard load for that specific energy source (i.e. the case “Normal wash, 40C”).

Looking at the figure, it seems that the emissions from domestic laundry could be decreased by 6-12% in regions with hard water in Sweden (provided that the clothes do not get damaged) by washing at higher temperatures and with less detergent. However, in areas with soft water the net change in GHG emissions would instead be zero. What is also interesting is that for European countries that mainly use non-renewable energy sources, the trade-off would instead lead to an increase in GHG emissions (regardless of the amount of detergent used). Lastly, it is fascinating to note how little change a decrease in program temperature from 40°C to 30°C results in (approximately 2-8%), no-matter the background energy source.

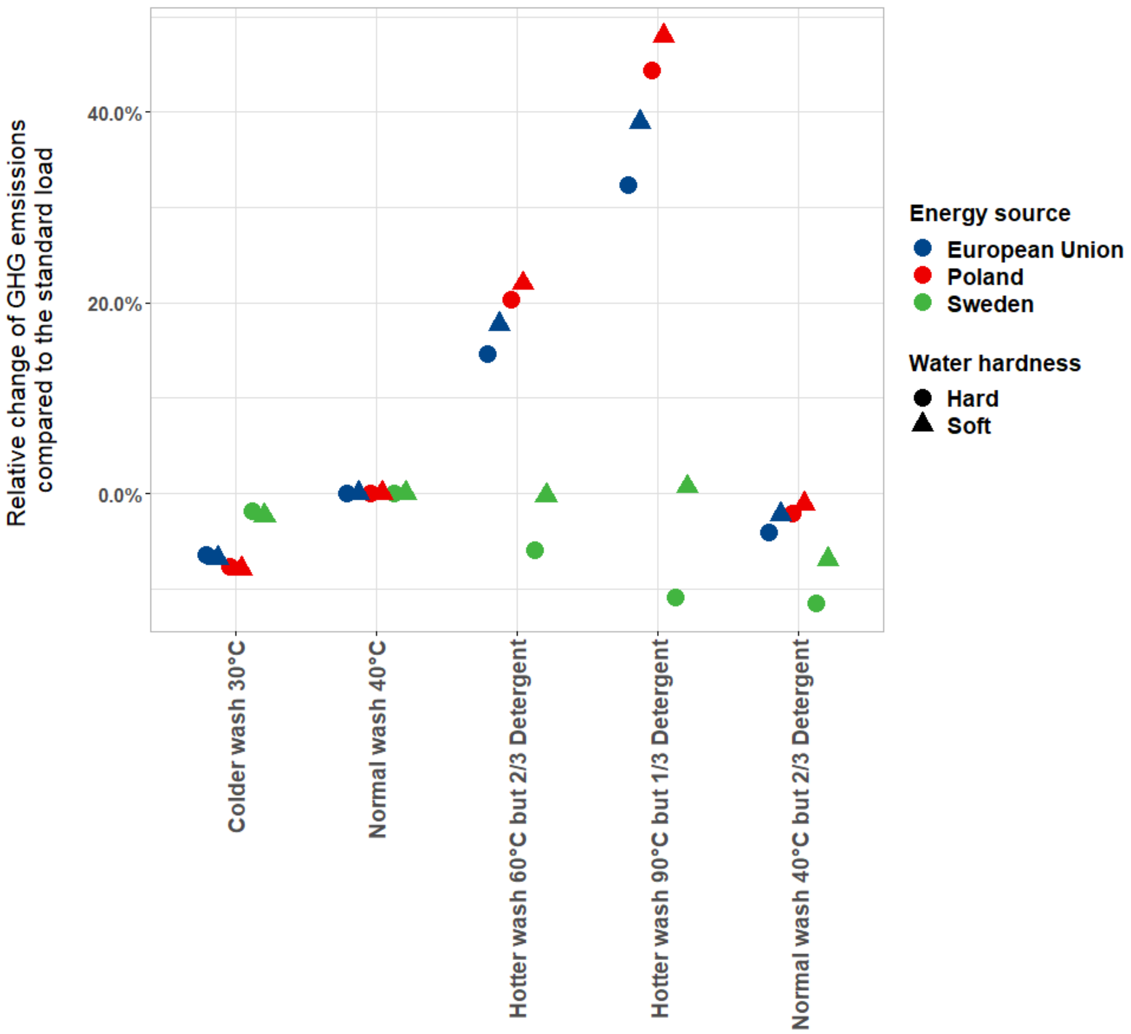

Fig 9. Resulting change of GHG emissions for trade-offs between detergent and temperature. Uncertainties affecting the result is mainly detergent dose as a function of water hardness. The baseline for each comparison is the emissions associated with the case "Normal Wash 40°C".

5.2. There is more to laundering than just cleaning clothes

Shifting focus away from the technical system and instead looking at the consumers themselves, it is apparent that laundering behaviour is shaped by more than just our need for clean clothes. As illustrated in the introduction, Shove (2003a) divides practices within sociotechnical systems into three elements: (1) the sociotechnical systems, collective conventions and arrangements; (2) the symbolic and material qualities of sociotechnical devices/objects; and (3) the habits, practices and expectations of users and consumers. This division can thus be used to categorize the findings in the second article into three new categories: technology, social conventions, and individual concerns. However, as noted by Shove, Pantzar, and Watson (2012) is not necessarily the content within each category that is interesting, but rather the co-evolution and interactions, i.e. "dimensions" (see Fig 3), between these three elements. By looking more closely on these dimensions, three general principles can be identified regarding laundry practices:

Principle 1: Technology changes conventions, while social context dictates market acceptance of new cleaning technology. While "cleanliness" once meant sanitized (i.e., without bacteria) the concept of laundry cleanliness has recently been shifting towards a broader meaning of "whiteness" (Shove 2003b). This change in definition not only relates to laundry detergent recipes (e.g. the introduction of optical brightener technologies which reached widespread adoption during the second half of the 20th century (Mustalish 2013)) but could also influence the use period for the clothes themselves (e.g., consumers discard clothes due to stains that are not removed by the washing machine). At the same time, social conventions might sometimes work as a barrier toward the general acceptance of washing machines to begin with. This situation could be seen in Soweto, where washing machines had become a symbol of laziness and by extension limited private ownership (Meintjes 2001).

Principle 2: Technological solutions are often suggested to influence laundry behaviour, but individual concerns seem to override the effect of the interventions. A common trait in the reviewed literature was that technological solutions often are proposed to steer consumer behaviour towards more environmentally beneficial laundering decisions. These types of suggestions often stems from the assumption that the consumers lack adequate knowledge, or that they act in irrational ways when interacting with technology (Wilk 2016). For example, Harris, Roby, and Dibb (2016) suggest that consumers need more information, as well as education, about the technical and chemical aspects for clothes care (e.g. to communicate time, money and labour savings from changed laundering practices). However, regardless of what type of technology is available for the consumer, habits rather than intentions seem to guide behaviour (Labrecque et al. 2017, Garling 1992). Thus, any intentions of behavioural change for laundering practices must consider already existing habits for a successful implementation. In addition, an individual's intentions to change also seem to be trumped by expressed individual concerns (e.g. anxiety about damage or poor wash results, or self-identification with ownership of private washing machine).

Principle 3: Consumer laundry practices are guided by social conventions that are rooted in intrapersonal dynamics. From the literature it is obvious that social conventions of how laundry should be sorted steer practices and influence judgment. For example, mixing pants and underwear with a tablecloth when washing would be considered most inappropriate in Brazil but not in Sweden. In addition, social conventions were evoked as the main reason for specific behaviours by the majority of the participants interviewed by Mylan and Southerton (2018), as well as the underlying reason for historical changes in laundering practice investigated by (Klepp 2003). In turn, some of these conventions might be rooted in attitudes and norms driven by underlying psychological processes. For example, several studies have identified individual concerns regarding sweat and odour as a guiding principle for dirty laundry evaluation (Jack 2013, Pink 2005, Mylan and Southerton 2018), and the fear of smelling has been stated as the main motivator to change clothes regularly (Gram-Hanssen 2007). This type of behaviour might not come as a surprise given that olfactory sensations seems to be used for first impression formation (Worrall et al. 1974), personality assessment (Kerr, Rosero, and Doty 2005), and during formations of social identity (Coppin et al. 2016). Additionally, smell seems to elicit social suspicion or cooperation (Lee and Schwarz 2012), could be used as a basis for social exclusion (Hodson and Costello 2007, Speltini and Passini 2014), and might also function as a signal for close social relationships (Schnall 2011). Taking all of this into account would mean that the fear of smelling could drive (and steer) cleanliness practices regarding laundering, provided that olfactory sensations are recognized as important by the social context. Although speculative, it might be that odour is considered less of a problem in cultures that uses lot of spices in their food or are situated in very humid places (making sweating unavoidable).

The overarching structure of these three principles is illustrated by Fig 10.

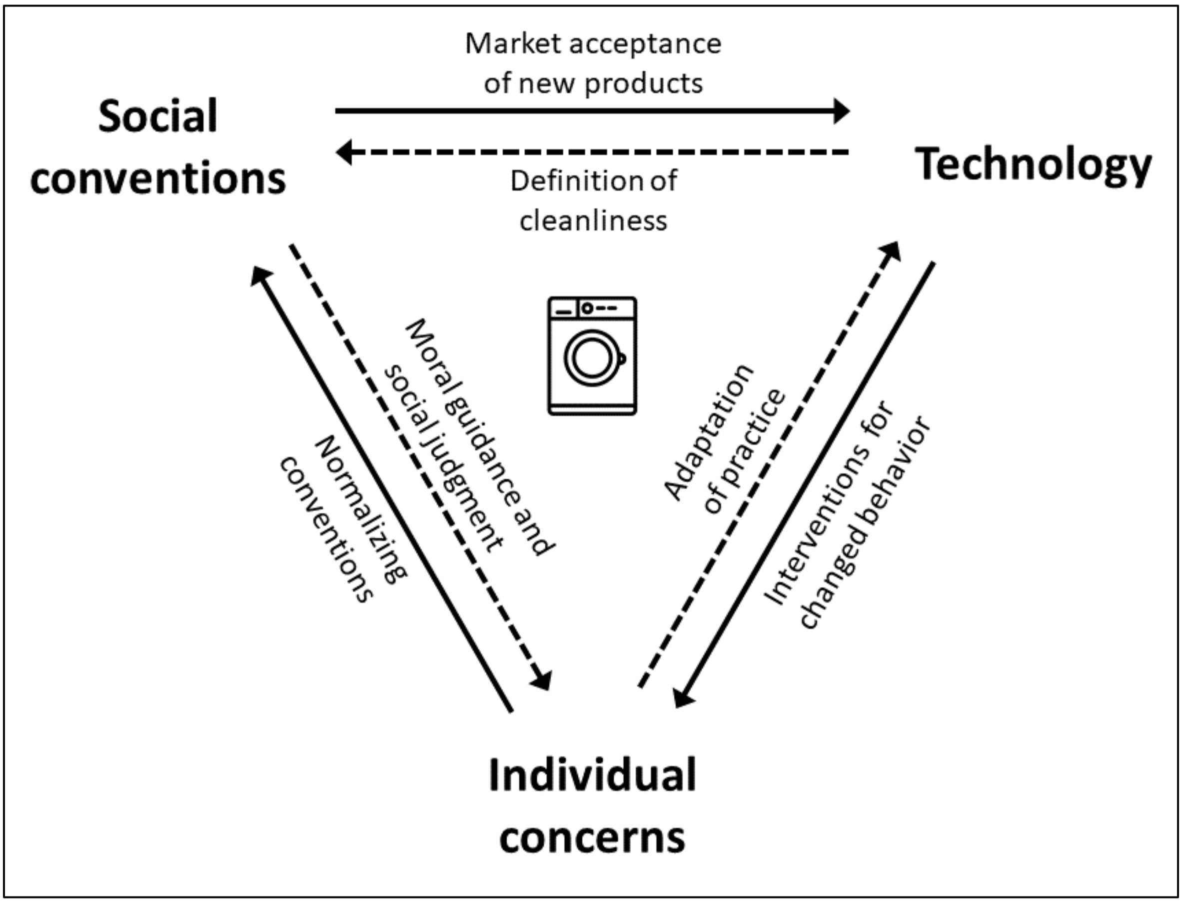

Fig 10. Suggested dimensions between social conventions, individual concerns, and technology that shape final laundering behaviour. Arrows indicate the direction of the influence.

Looking at the reviewed literature in more detail, the majority of research identified in Article 2 (and by extension their suggestions for policy and interventions) concerns the dimension between technology and social conventions, as well as the dimension between technology and individual concerns (i.e. principle 1 and 2). However, only a few articles suggest interventions for sustainable practice that also address the individual's fear of social judgment (i.e. principle 3).

If there is a tension between these potential drivers, some of the previous interventions regarding laundering might thus indirectly have forced consumers to choose between social risk and environmental emissions. Additionally, since few consumers seem to think that laundering practice is coupled with emissions, there is no incentive for behavioural change.

Lastly, as proposed in Fig 10, the dimensions of the third principle go two ways: the consumer is guided by the experienced social conventions (implicit or explicit), while at the same time upholding and passing on these same unwritten rules. However, some of the findings in the review suggest that this normalization of laundry practice might also be a result of personal psychological traits (e.g. fear of moral transgressions). If this turns out to be true, it will further explain why changing laundering practices seems so hard for many consumers.

6. CONCLUSIONS

Based on the finding in Article 1 and 2, the following answers can be derived for the three research questions posed in the beginning of this licentiate.

RQ1 – *To what extent do capital goods (i.e. whitegoods and the building itself) influence the emissions associated with domestic laundry in Sweden, and how do they vary between private and shared laundry systems?*

When calculating the emissions associated with doing the laundry using a privately owned machine, capital goods contributed approximately 38% of the estimated GHG emissions. Additionally, capital goods were the largest or second largest contributor to more than half of all the other impact categories. For the shared systems, capital goods contributed much less to the final result, although they were not negligible (11-16% of the estimated GHG emissions). The results from Article 1 also indicate that using a shared laundry instead of a private machine leads to a reduction of emissions by approximately 26%, mainly due to the reduced amount of capital goods.

However, it should be mentioned that the LCA model used in Article 1 assumes similar consumer behaviours in the private and shared laundry systems (e.g. choice of wash programs and filling ratio of the machine). From personal experience this assumption might not be true in real life. The practical restraints common for shared laundries (e.g. booking time, physical location of the washing room, or the price of running a machine) usually favour decisions towards a larger laundry load and a much higher filling rate. Similarly, owning your own washing machine allows for a more *laissez-faire* attitude towards laundry which in turn might increase the number of washes per month, as well as quicker washes with fewer items (e.g. washing your training clothes after working out). Although the prevalence of these types of behaviours must be further investigated, it is not unreasonable to believe that the 26% difference in levels of emissions is an understatement.

It is evident that capital goods play a much bigger role for environmental impacts from laundry practices than previously thought. Or rather that the continuous product developments and efficiency measures for detergent and energy use have reduced the relative importance of these two categories, compared to capital goods. Unfortunately, since capital goods are still often neglected in LCA, the findings in Article 1 also mean that many estimations of emissions from laundering, as well as all estimates of emissions from textile that are washed (e.g. clothes), are underestimates.

RQ2 – *How could net emissions potentially change in Sweden, as well as in other EU countries, on account of the trade-off between temperature and detergent dose?*

Contrary to common beliefs, the findings in Article 1 suggest that for many Swedish consumers it would be beneficial to launder at *higher* temperature but with less detergent. This is especially true for people using a large amount of detergent for each wash cycle, as often the case when living in areas with hard water. By extension, this finding means that we are starting to reach a point with diminishing returns from energy efficient measures for washing machines. Of greater importance are instead measures for reducing the environmental impacts from detergents, as well as a more widespread transition to a fossil-free grid mix.

RQ3 – *What underlying factors shape contemporary laundry behaviour?*

Based on the reviewed research literature, behaviour of individuals in the laundry are influenced by more aspects than just the available technology and temporal constraints. This means that consumer decisions regarding laundry practices will be influenced both by technology as well as social conventions. Additionally, final behaviour might also be influenced by psychological aspects of cleanliness and smell, although this needs to be investigated further. Looking at laundry from a sociotechnical perspective, three general principles can be suggested based on the findings in the mapping review: (1) technology changes conventions while social context dictates technology acceptance; (2) technological solutions are often suggested to influence behaviour but individual concerns seem to override the effect of such interventions; and (3) consumer practices are often guided by social conventions rooted in attitudes and norms driven by underlying psychological processes.

7. CONSEQUENCES FOR POLICY

The findings presented in this licentiate have implications for policy. For example, the majority (around 80%-100%) of all new multi-family buildings built in major cities in Sweden has since the year 2012 been equipped with privately-owned machines, forgoing the shared laundry room (Borg and Hogberg 2014). Based on the result in Article 1, it is clear that it would be beneficial from an environmental point of view to introduce policies to reverse that trend. It is also important to mention that reclaiming the shared laundry room concept for multi-family houses could also lead to more efficient use of building space. This would mean that there are economic incentives for shared laundries (especially in densely populated cities), provided that the laundry rooms are designed in an appealing way for consumers (Amasawa et al. 2018). Given the research presented in this licentiate, the first suggestions for limiting emissions from domestic laundering practices thus include:

1. *Introduce policies that require shared laundries when building new multi-family houses in Sweden.* This is especially crucial for companies operating public housing (46% of all Swedish rental apartments) since they have a stated mission to run the rental business in an environmental, economic, and social sustainable way (Public Housing Sweden 2020, Hall, Löfgren, and Peters 2016). With such a stated mission, it is also unclear why this type of policy is not already included in the building standards for public housing companies, though a lack of knowledge is often cited as a barrier for general procurement practices (Hall, Löfgren, and Peters 2016).
2. *Initiate political programs that facilitate market-penetration for private pay-per-use services.* This is important since many existing multi-family buildings have physical constraints that might limit an introduction of shared laundries. In these situations one alternative might be to use a private pay-per-use services (e.g. where you do not own the machine in your apartment and only pay when using it) since these alternative business models seem to push consumers towards fewer washes at lower temperature (Bocken et al. 2018). However, it should be noted that the extent of reduced environmental impacts associated with these services have not yet been clarified and further research for these types of services are warranted.

Historically speaking, policies concerning domestic laundry in Sweden and in Europe have mainly focused on making laundry machines more energy efficient. This has in turn resulted in huge technological advancements over the last decade (Graulich et al. 2011, Presutto et al. 2007), marketing campaigns (Morgan, Foxon, and Tallontire 2018), and behavioural shifts towards washing at lower temperatures (Laitala, Klepp, and Boks 2012). However, since the current environmental labelling systems for washing machines in Europe are mainly focused on energy consumption rather than emissions, an energy efficient washing machine run in Sweden could lead to higher levels of emissions than a "normal" machine run at a higher temperature (but with less detergent). There are of course some possible solutions to this dilemma:

3. Expand the system boundary for the environmental labelling systems in Europe so that it also includes possible trade-offs between variables that are co-dependent (e.g. temperature and detergent). This is especially important since many countries are starting to wean their electricity sectors off non-renewable fuels, which over time will

decrease the relative importance of additional energy efficient measures for laundering technology.

4. Another possible initiative would be to inform and educate consumers within countries with mainly renewable energy sources (e.g. the Nordic countries) about this dynamic so that they themselves can make informed decisions. However, due to the findings in Article 2, it is unclear how big changes in behaviour such an initiative would generate.

Finally, related to this trade-off between energy and detergent, anecdotal evidence of the role of the fashion industry emerged during the writing for Article 1. Apparently, some clothing companies seem to be contemplating reducing the recommended wash temperature on their clothing care instructions for environmental reasons (rather than the delicacy of the specific clothing item). If this rumour turns out to be true it would be of great interest if this type of action could be avoided in the future, meaning that stakeholder dialogue is crucial.

8. FUTURE RESEARCH

This licentiate is based on two articles aiming to address the challenges with reducing emissions connected to domestic laundering from two different perspectives: the conditions for the technical system itself as well as broad factors influencing consumer behaviour. Since there are obvious overlaps between the findings (as indicated by the conclusions and suggestions in the previous chapters), a natural continuation of the research is to further investigate the most crucial parts of these overlaps.

For example, a major uncertainty in the LCA-model used in Article 1 is assumed to be consumer behaviour. Given that laundry regimes are a socially and morally loaded subject (i.e. the findings from Article 2), an inevitable conclusion is to question whether or not the underlying data used in the LCA model can be trusted. For example, data concerning loading rate, wash frequency and detergent dosage are almost exclusively collected by using surveys. However, digging deeper into the underlying material, few of the data collections (if any) seem to address common sources for error regarding surveys such as: self-reporting bias, conformity bias, and implicit sociable likeness biases. One way to address this would be to compare self-reported data with actual behaviour, investigating to what extent our own perception of our behaviour influence survey results. The findings from such a work could then be used to better describe the uncertainty and variability of the LCA model used in Article 1. Additionally, as noted in the introduction, is also interesting to look at domestic laundering from the perspective of clothing consumption in general. Another possible continuation of this research would thus be to further extend the system boundary for the LCA model to also include potential changes in garment life-length, as a result of consumer decisions in the laundry (e.g. wash frequency or choice of temperature).

A second major theme that presently has not been investigated thoroughly is the psychological aspect of laundry. Although some of these aspects are mentioned in Article 2, most of the findings are suggestive, based on circumstantial findings connecting articles from sociology and technology with psychological concepts of cleanliness and dirtiness. For example, while sociological papers suggest a connection between wash frequencies for laundering and social norms, actual psychological testing of the hypothesis are missing. One way to address this would be to design a survey experiment that both tries to capture psychological traits (e.g. sensibility to concepts of cleanliness or social norms), as well as perceived behaviour. Or better yet, combining a psychological investigation with actual individualised laundering data. This would probably be possible to achieve in collaboration with a company that delivers a private pay-per-wash service, or by collecting data from clothes that are equipped with personalized RFID-tags (provided the tags can be read by the machines). Regardless, while these psychological aspects are very interesting, the practical challenge of how to collect a crucial amount of relevant data in a real-life setting should not be underestimated.

On a similar note, only a few articles in the reviewed literature suggest sustainability interventions that address the individual’s fear of social judgment. Although speculative, this might have indirectly forced consumers to choose between social risk and environmental emissions. One possible avenue for future research could thus be to investigate if this dynamic exists, what psychological traits are activated, and if these tendencies (if properly addressed) could be used to change behaviour. Although on a small scale, it should be noted that two such examples have already been tried by Jack (2013) and Sahakian (2019) with promising results. Additional examples could be social campaigns that try to establish shabby clothes as a signal of environmental righteousness, or "challenging" consumers to altered behaviours (i.e. providing an "excuse" to try new ways of doing the laundry).

More generally, it seems that there exist several misconceptions amongst consumers related to the practice. Since some of these misconceptions seem to hinder behavioural change, the underlying reasons for these false beliefs should be investigated. Of special interest are the misperceptions regarding the cleaning capabilities and energy saving properties of eco-programs installed in modern washing machines (Alborzi, Schmitz, and Stamminger 2017). This is especially interesting in relationship to why some consumers also seem to think that short cycles lead to lower emissions (Sahakian 2019). Additionally, it would also be interesting to investigate why many consumers do not believe that laundering practices lead to environmental emissions (Arild 2003).

Lastly, there exist some other research questions related to theme of misconceptions that would be beneficial to address. One such example is the underlying reasons for the changed focus within the building sector in Sweden (i.e. the trend of installing in-unit machines rather than shared laundries). When asked, many developers state that this is a result of changed consumer preferences, although many tenants do not agree when asked. Since this seems to be one of the most common stated reasons for changed building design, the truthfulness in these motivations should be investigated. Additionally, if these preferences turn out to be true for specific consumer groups (e.g. older people that used to live in their own free-standing house) potential alternative designs for shared laundry rooms should be investigated. For example, the majority of shared laundries in Sweden are typically one large facility per building. However, alternative set-ups might sometimes be better suited depending on the tenants, such as a smaller facility on each floor or in-house professional laundering businesses.

REFERENCES

Alborzi, F., A. Schmitz, and R. Stamminger. 2017. "Long wash cycle duration as a potential for saving energy in laundry washing." 10 (4). doi: 10.1007/s12053-016-9486-z.

Amasawa, E., Y. Suzuki, D. Moon, J. Nakatani, H. Sugiyama, and M. Hirao. 2018. "Designing Interventions for Behavioral Shifts toward Product Sharing: The Case of Laundry Activities in Japan." *Sustainability* 10 (8):20. doi: 10.3390/su10082687.

Anderson, S., P. Allen, S. Peckham, and N. Goodwin. 2008. "Asking the right questions: Scoping studies in the commissioning of research on the organisation and delivery of health services." *Health Research Policy and Systems* 6 (1):7. doi: 10.1186/1478-4505-6-7.

Arild, A.-H. B., R.; Halvorsen-Gunnarsen, J.T.; van Kessel, I.A.C.; Terpstra, P. M. J.;. 2003. An Investigation of domestic Laundry in Europe – Habits, Hygiene and Functional Performance.

Bartiaux, F. 2008. "Does environmental information overcome practice compartmentalisation and change consumers' behaviours?" *Journal of Cleaner Production* 16 (11):1170-1180. doi: 10.1016/j.jclepro.2007.08.013.

Baumann, H., and A.-M. Tillman. 2004. *The hitchhiker's guide to LCA : an orientation in life cycle assessment methodology and application*: Studentlitteratur. Non-fiction.

Bocken, N. M. P., R. Mugge, C. A. Bom, and H.-J. Lemstra. 2018. "Pay-per-use business models as a driver for sustainable consumption: Evidence from the case of HOMIE." *Journal of Cleaner Production* 198:498-510. doi: 10.1016/j.jclepro.2018.07.043.

Booth, A. 2016. "EVIDENT Guidance for Reviewing the Evidence: a compendium of methodological literature and websites." *Unpublished*. doi: 10.13140/RG.2.1.1562.9842.

Borg, L., and L. Hogberg. 2014. "Organization of Laundry Facility Types and Energy Use in Owner-Occupied Multi-Family Buildings in Sweden." *Sustainability* 6 (6):3843-3860. doi: 10.3390/su6063843.

Budgen, D., M. Turner, P. Brereton, and B. Kitchenham. 2008. "Using Mapping Studies in Software Engineering." Proc. PPIG.

Conrady, T., A. Kruschwitz, and R. Stamminger. 2013. "Influencing the sustainability of washing behavior by using motivational interviewing." *Energy Efficiency* 7 (2):163-178. doi: 10.1007/s12053-013-9215-9.

Coppin, G., E. Pool, S. Delplanque, B. Oud, C. Margot, D. Sander, and J. J. Van Bavel. 2016. "Swiss identity smells like chocolate: Social identity shapes olfactory judgments." *Sci Rep* 6:34979. doi: 10.1038/srep34979.

Ekvall, T. 2020. "Attributional and consequential life cycle assessment." In *Sustainability Assessment at the 21st century*, edited by M.J. Bastente-Ceca, L.J. Fuentes Bargues, L. Hufnagel, F.-C. Mihai and C. Latu, 41-62.

European Commission. 2019. COMMISSION STAFF WORKING DOCUMENT EXECUTIVE SUMMARY OF THE EVALUATION of Regulation (EC) No 648/2004 of the European Parliament and of the Council of 31 March 2004 on detergents.

Finnveden, G., and Å. Moberg. 2005. "Environmental systems analysis tools – an overview." *Journal of Cleaner Production* 13 (12):1165-1173. doi: https://doi.org/10.1016/j.jclepro.2004.06.004.

Garling, T. 1992. "The Importance of Routines for the Performance of Everyday Activities." *Scandinavian Journal of Psychology* 33 (2):170-177. doi: DOI 10.1111/j.1467-9450.1992.tb00896.x.

Gram-Hanssen, K. 2007. "Teenage Consumption of Cleanliness: How to Make It Sustainable?" *Sustainability: Science, Practice, & Policy* 3 (2):15.

Grant, M. J., and A. Booth. 2009. "A typology of reviews: an analysis of 14 review types and associated methodologies." *Health Info Libr J* 26 (2):91-108. doi: 10.1111/j.1471-1842.2009.00848.x.

Graulich, K., M. Blepp, E. Brommer, C.-O. Gensch, and I. Rüdenauer. 2011. Preparatory Studies for Eco-design Requirements of Energy-using Products - Lot 24: Professional Washing Machines, Dryers and Dishwashers. Task 6: Technical Analysis Best Available Technologies

Hahnel, U. J. J., G. Chatelain, B. Conte, V. Piana, and T. Brosch. 2020. "Mental accounting mechanisms in energy decision-making and behaviour." *Nature Energy* 5 (12):952-958. doi: 10.1038/s41560-020-00704-6.

Hall, P., K. Löfgren, and G. Peters. 2016. "Greening the Street-Level Procurer: Challenges in the Strongly Decentralized Swedish System." *Journal of Consumer Policy* 39 (4):467-483. doi: 10.1007/s10603-015-9282-8.

Harris, F., H. Roby, and S. Dibb. 2016. "Sustainable clothing: challenges, barriers and interventions for encouraging more sustainable consumer behaviour." *International Journal of Consumer Studies* 40 (3):309-318. doi: 10.1111/ijcs.12257.

Hauschild, M. Z., R. K. Rosenbaum, and S. I. Olsen. 2018. *Life Cycle Assessment. [electronic resource] : Theory and Practice*. 1st ed. 2018. ed: Springer International Publishing. eBook.

Hodson, G., and K. Costello. 2007. "Interpersonal disgust, ideological orientations, and dehumanization as predictors of intergroup attitudes." *Psychol Sci* 18 (8):691-8. doi: 10.1111/j.1467-9280.2007.01962.x.

ISO. 2006. Environmental management - Life cycle assessment - Principles and framework. In *14040:2006*: European Committee for Standardization.

Ivanova, D., K. Stadler, K. Steen-Olsen, R. Wood, G. Vita, A. Tukker, and E. G. Hertwich. 2016. "Environmental Impact Assessment of Household Consumption." *Journal of Industrial Ecology* 20 (3):526-536. doi: 10.1111/jiec.12371.

Jack, T. 2013. "Nobody was dirty: Intervening in inconspicuous consumption of laundry routines." *Journal of Consumer Culture* 13 (3):406-421. doi: 10.1177/1469540513485272.

Järvi, P., and A. Paloviita. 2007. "Product-related information for sustainable use of laundry detergents in Finnish households." *Journal of Cleaner Production* 15 (7):681-689. doi: https://doi.org/10.1016/j.jclepro.2005.12.001.

Kerr, K. L., S. J. Rosero, and R. L. Doty. 2005. "Odors and the perception of hygiene." *Percept Mot Skills* 100 (1):135-41. doi: 10.2466/pms.100.1.135-141.

Klepp, I. G. 2003. "Clothes and Cleanliness - Why We Still Spend As Much Time on Laundry." *Ethnol Scand* 33.

Labrecque, J. S., W. Wood, D. T. Neal, and N. Harrington. 2017. "Habit slips: when consumers unintentionally resist new products." *Journal of the Academy of Marketing Science* 45 (1):119-133. doi: 10.1007/s11747-016-0482-9.

Laitala, K., I. G. Klepp, and C. Boks. 2012. "Changing laundry habits in Norway." *Int J Consum Stud* 36 (2):228-237. doi: 10.1111/j.1470-6431.2011.01081.x.

Laitala, K., I. G. Klepp, R. Kettlewell, and S. Wiedemann. 2020. "Laundry Care Regimes: Do the Practices of Keeping Clothes Clean Have Different Environmental Impacts Based on the Fibre Content?" *Sustainability* 12 (18). doi: 10.3390/su12187537.

Lee, S. W., and N. Schwarz. 2012. "Bidirectionality, mediation, and moderation of metaphorical effects: the embodiment of social suspicion and fishy smells." *J Pers Soc Psychol* 103 (5):737-49. doi: 10.1037/a0029708.

Liljenström, C., T. Malmqvist, M. Erlandsson, J. Fredén, I. Adolfsson, G. Larsson, and M. Brogren. 2015. Byggandets klimatpåverkan - Livscykelberäkning av klimatpåverkan och energianvändning för ett nyproducerat energieffektivt flerbostadshus i betong. Stockholm.

Lund, K. 2009. *Tvättstugan : en svensk historia*: Nordiska museets förlag. Non-fiction.

Madsen, B., S. Perumalpillai, S. Selby, and S. Aumônier. 2007. Mapping of Evidence on Sustainable Development Impacts that Occur in Life Cycles of Clothing: A Report to the Department for Environment. London.

McManus, M. C., and C. M. Taylor. 2015. "The changing nature of life cycle assessment." *Biomass and Bioenergy* 82:13-26. doi: https://doi.org/10.1016/j.biombioe.2015.04.024.

McQueen, R. H., J. C. Batcheller, L. J. Moran, H. Zhang, and P. M. Hooper. 2017. "Reducing laundering frequency to prolong the life of denim jeans." *International Journal of Consumer Studies* 41 (1):36-45. doi: 10.1111/ijcs.12311.

Meintjes, H. 2001. "'Washing Machines Make Lazy Women'." *Journal of Material Culture* 6 (3):345-363. doi: 10.1177/135918350100600304.

Miilunpalo, S. M., and R. Raisanen. 2019. "Clean laundry with pure conscience-A study on laundry practices among Finnish consumers." *International Journal of Consumer Studies* 43 (2):153-165. doi: 10.1111/ijcs.12493.

Moazzem, S., F. Daver, E. Crossin, and L. Wang. 2018. "Assessing environmental impact of textile supply chain using life cycle assessment methodology." *The Journal of The Textile Institute* 109 (12):1574-1585. doi: 10.1080/00405000.2018.1434113.

Moher, D., A. Liberati, J. Tetzlaff, D. G. Altman, and P. Group. 2009. "Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement." *PLoS Med* 6 (7):e1000097. doi: 10.1371/journal.pmed.1000097.

Mont, O., and A. Plepys. 2007. "System Perspective on Service Provision: A case of community-based washing centres for households." *Int J Publ Aff* 3:130-151.

Moon, D., E. Amasawa, and M. Hirao. 2020. "Consumer motivation and environmental impact of laundry machine-sharing: Analysis of surveys in Tokyo and Bangkok." 12 (22).

Morgan, E., T. J. Foxon, and A. Tallontire. 2018. "'I prefer 30 degrees'?: Business strategies for influencing consumer laundry practices to reduce carbon emissions." *J Clean Prod* 190:234-250. doi: 10.1016/j.jclepro.2018.04.117.

Mustalish, R. A. 2013. "Optical brighteners: history and technology." *Studies in Conservation* 45 (sup1):133-136. doi: 10.1179/sic.2000.45.Supplement-1.133.

Muthu, S. S. 2015. "Environmental impacts of the use phase of the clothing life cycle (Ch 5)." In *Handbook of Life Cycle Assessment (LCA) of Textiles and Clothing*, edited by Subramanian Senthilkannan Muthu, 93-102. Woodhead Publishing.

Mylan, J., and D. Southerton. 2018. "The Social Ordering of an Everyday Practice: The Case of Laundry." *Sociology-the Journal of the British Sociological Association* 52 (6):1134-1151. doi: 10.1177/0038038517722932.

Nash, N., L. Whitmarsh, S. Capstick, T. Hargreaves, W. Poortinga, G. Thomas, E. Sautkina, and D. Xenias. 2017. "Climate-relevant behavioral spillover and the potential contribution of social practice theory." *WIREs Climate Change* 8 (6):e481. doi: https://doi.org/10.1002/wcc.481.

Pakula, C., and R. Stamminger. 2010. "Electricity and water consumption for laundry washing by washing machine worldwide." *Energy Effic* 3 (4):365-382. doi: 10.1007/s12053-009-9072-8.

Pakula, C., and R. Stamminger. 2015. "Energy and water savings potential in automatic laundry washing processes." *Energy Efficiency* 8 (2):205-222. doi: 10.1007/s12053-014-9288-0.

Peters, G. M., G. Sandin, and B. Spak. 2019. "Environmental Prospects for Mixed Textile Recycling in Sweden." *Acs Sustain Chem Eng* 7 (13):11682-11690. doi: 10.1021/acssuschemeng.9b01742.

Petticrew, M., H. Roberts, and I. Wiley. 2006. *Systematic Reviews in the Social Sciences : A Practical Guide*. Malden, MA: Wiley-Blackwell. Book.

Pink, S. 2005. "Dirty laundry. Everyday practice, sensory engagement and the constitution of identity." *Social Anthropology* 13 (3):275-290.

Presutto, M., R. Stamminger, R. Scaldoni, W. Mebane, and R. Esposito. 2007. Preparatory Studies for Eco-design requirements of EuPs; Lot 14: Domestic washing machines and dishwashers; Task 1–2.

PricewaterhouseCoopers. 2009. Ecodesign of Laundry Dryers: Preparatory studies for Ecodesign requirements of Energy-using-Products (EuP) - Lot 16.

Public Housing Sweden. 2020. The public housing sector moving towards 2030 - A concept programme.

Retamal, M., and H. Schandl. 2018. "Dirty Laundry in Manila: Comparing Resource Consumption Practices for Individual and Shared Laundering." *J Ind Ecol* 22 (6):1389-1401. doi: 10.1111/jiec.12696.

Rotocon. 2019. Fintvättstuga med två tvätt-avdelningar. Rotocon AB.

Sahakian, M. 2019. "'More, bigger, better' household appliances: Contesting normativity in practices through emotions." *Journal of Consumer Culture*. doi: 10.1177/1469540519889983.

Saouter, E., and P. White. 2002. "Laundry Detergents: Cleaner Clothes and a Cleaner Environment." *Corporate Environmental Strategy* 9 (1):40-51. doi: https://doi.org/10.1016/S1066-7938(01)00149-X.

Schnall, S. 2011. "Clean, Proper and Tidy Are More Than the Absence of Dirty, Disgusting and Wrong." *Emotion Review* 3 (3):264-266. doi: 10.1177/1754073911402397.
Shahmohammadi, S., Z. Steinmann, J. Clavreul, H. Hendrickx, H. King, and M. A. J. Huijbregts. 2017. "Quantifying drivers of variability in life cycle greenhouse gas emissions of consumer products—a case study on laundry washing in Europe." *Int J Life Cycle Ass* 23 (10):1940-1949. doi: 10.1007/s11367-017-1426-4.
Shove, E. 2003a. *Comfort, Cleanliness and Convenience : The Social Organization of Normality*. London, UNITED KINGDOM: Bloomsbury Publishing.
Shove, E. 2003b. "Converging conventions of comfort, cleanliness and convenience." *Journal of consumer policy* 26 (4):395-418.
Shove, E., M. Pantzar, and M. Watson. 2012. *The dynamics of social practice: everyday life and how it changes*: Sage Publications.
Sinner, H. 1960. *Über das Waschen mit Haushaltwaschmachinen.*: Haus&Heim Verlag.
Speltini, G., and S. Passini. 2014. "Cleanliness/dirtiness, purity/impurity as social and psychological issues." *Culture & Psychology* 20 (2):203-219. doi: 10.1177/1354067x14526895.
Stamminger, R., A. Barth, and S. Dörr. 2005. "Old washing machines wash less efficiently and consume more resources." *Hauswirtsch Wiss* (3):124-131.
Throne-Holst, H., P. Strandbakken, and E. Stø. 2008. "Identification of households' barriers to energy saving solutions." *Management of Environmental Quality: An International Journal* 19 (1):54-66. doi: 10.1108/14777830810840363.
Tillman, A. M. 2000. "Significance of decision-making for LCA methodology." *Environmental Impact Assessment Review* 20 (1):113-123. doi: 10.1016/S0195-9255(99)00035-9.
Treas, J., and T. Tai. 2016. "Gender Inequality in Housework Across 20 European Nations: Lessons from Gender Stratification Theories." *Sex Roles* 74 (11-12):495-511. doi: 10.1007/s11199-015-0575-9.
Tukker, A. 2015. "Product services for a resource-efficient and circular economy – a review." *J Clean Prod* 97:76-91. doi: 10.1016/j.jclepro.2013.11.049.
Uitdenbogerd, D. E. 2007. "Energy and households : the acceptance of energy reduction options in relation to the performance and organisation of household activities = De acceptatie van energie reductieopties in relatie tot de uitvoering en organisatie van huishoudelijke activiteiten."
Wang, L. L., X. M. Ding, R. Huang, and X. Y. Wu. 2014. "Choices and using of washing machines in Chinese households." *Int J Consum Stud* 38 (1):104-109. doi: 10.1111/ijcs.12070.
Wiedemann, S. G., L. Biggs, B. Nebel, K. Bauch, K. Laitala, I. G. Klepp, P. G. Swan, and K. Watson. 2020. "Environmental impacts associated with the production, use, and end-of-life of a woollen garment." *The International Journal of Life Cycle Assessment* 25 (8):1486-1499. doi: 10.1007/s11367-020-01766-0.
Wilk, R. 2016. Anxious appetites: food and consumer culture. Bloomsbury Academic.
Worrall, N., V. M. Taylor, J. P. Ricketts, and A. P. Jones. 1974. "Personal Hygiene Cues in Impression Formation." *Perceptual and Motor Skills* 38 (3):1269-1270. doi: DOI 10.2466/pms.1974.38.3c.1269.
Yates, L., and D. Evans. 2016. "Dirtying Linen: Re-evaluating the sustainability of domestic laundry." *Environmental Policy and Governance* 26 (2):101-115. doi: 10.1002/eet.1704.